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Teacher competencies and digital integration into teaching practices: perceptions from pre-service biology teachers in Kazakhstan

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This study investigates the self-reported teaching competencies, attitudes, and digital content usage of pre-service biology teachers in Kazakhstan. Competencies in this study refer specifically to the teachers' levels of pedagogical knowledge, content knowledge, and technological knowledge, as conceptualized by the Technological Pedagogical Content Knowledge (TPACK) framework. The research also examines how these self-reported competencies relate to demographic variables (gender, grade level, institutional affiliation, and stipend status) and institutional characteristics. Data were collected from 240 participants across three universities using two structured surveys. The findings indicate high self-reported competencies in TPACK domains, with significant variations in Technological Knowledge (TK) and digital content attitudes across gender, grade levels, and institutions. Female participants rated their competencies higher in multiple domains, while students in their final year of study exhibited greater scores in TPACK. Institutional differences were significant for the three different institutions. Stipend status was associated with minimal differences in most competencies, except for TK, where stipend recipients scored higher. Despite positive attitudes toward digital content, participants reported lower frequency of use and technological proficiency, indicating a gap between attitudes and practical application. Correlational analyses indicated that self-reported professional knowledge is closely linked to their digital content usage patterns and attitudes, stressing the interconnected nature of knowledge, behavior, and beliefs in the context of digital integration in education. These findings point out the need for targeted interventions, equitable resource allocation, and hands-on training in teacher preparation programs.

KEYWORDS

teacher competencies, digital integration, biology education, digital content usage, pre-service biology teachers

Introduction

In this study, the integration of digital content into education is transforming how teachers deliver lessons and engage students. Digital integration refers to the incorporation of digital content and tools into biology teaching practices, including lesson planning, instructional delivery, and assessment processes, with the aim of enhancing student engagement and learning outcomes. For biology education, digital tools such as simulations, virtual labs, and interactive resources provide unique opportunities to make abstract concepts more tangible and accessible. Imagine a biology classroom where students explore the intricate process of cellular respiration not through static textbook diagrams but by interacting with dynamic 3D simulations that visualize the flow of molecules through cellular membranes. These digital tools, ranging from virtual labs to augmented reality applications, enable learners to grasp complex submicroscopic processes that are otherwise difficult to observe. In biology education, such visual and interactive resources have emerged as powerful instruments for enhancing conceptual understanding, especially in topics like genetics, molecular biology, and ecosystems (Smetana and Bell, 2012; Rutten et al., 2012).

However, the mere availability of digital resources does not automatically translate into effective teaching. Teachers need to skillfully integrate these tools into their pedagogical practices, requiring a sophisticated blend of content knowledge, pedagogical strategies, and technological expertise, an integration conceptualized in the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra and Koehler, 2006). This raises a crucial question: How prepared are pre-service biology teachers to use digital content effectively, and how do their competencies, attitudes, and demographic backgrounds influence their actual use of such tools?

Although prior research highlights the significance of teacher competencies and attitudes in digital integration (Schmid et al., 2020; Ertmer et al., 2012; Tondeur et al., 2012), few studies have systematically investigated these factors within the specific context of biology education, especially among pre-service teachers. The relationship between teacher knowledge, demographic variables (e.g., gender, grade level, institutional affiliation), and digital content usage remains underexplored in this subject area. This study aims to fill this gap by examining pre-service biology teachers' self-reported knowledge, attitudes toward digital content, and digital content use, with particular attention to differences across gender, grade level, and institutional affiliation.

The novelty of this research lies in its dual focus: analyzing teacher knowledge and exploring how it interacts with attitudes and demographic diversity. Unlike prior studies that often examine these aspects in isolation, this research provides a comprehensive view of the factors influencing digital content integration.

Research questions

1. What is the level of professional knowledge (TPACK dimensions), attitudes, and digital content use among pre-service biology teachers in Kazakhstan?
2. Are there significant differences in professional knowledge, attitudes, and digital content use among pre-service biology teachers based on gender, institutional affiliation, and scholarship status?
3. What are the relationships between pre-service teachers' professional knowledge, attitudes, and digital content use?

The inclusion of institutional characteristics, specifically, institutional affiliation and scholarship status, was theoretically grounded in prior research emphasizing the role of institutional environments and financial resources in shaping technology-related teaching competencies. Studies such as Tondeur et al. (2012) and Kopcha (2012) have demonstrated that differences in institutional infrastructure, administrative support, and professional development opportunities can significantly impact teachers' technology integration practices. In Kazakhstan, universities vary considerably in terms of digital infrastructure, international collaboration, and pedagogical training approaches, which makes institutional affiliation a relevant variable for analysis (Grechi et al., 2025). Scholarship status was included to explore whether financial support influences access to digital tools and training, particularly in contexts where personal resources can affect educational experiences.

Theoretical background

In this study, we conceptualize teacher competence as an umbrella term encompassing cognitive, affective-motivational, and behavioral dimensions, consistent with established competence frameworks such as Baumert and Kunter's (2013) COACTIV model. According to this model, teacher competence includes professional knowledge (cognitive domain), motivational orientations and beliefs (affective-motivational domain), and professional behavior in instructional settings (behavioral domain). In line with this framework, we focus on three key components of pre-service biology teachers' competence regarding digital content integration: professional knowledge, which is operationalized through the TPACK framework (Mishra and Koehler, 2006); attitudes toward digital content, which reflect affective-motivational aspects such as teachers' enthusiasm, beliefs about digital tools' utility, and openness to new technologies; and digital content use, which represents behavioral manifestations, including the frequency and ways in which digital content is incorporated into teaching practices.

We adopted the full TPACK framework as developed by Mishra and Koehler (2006), which includes all seven components: content knowledge (CK), pedagogical knowledge (PK), technological knowledge (TK), pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and the comprehensive TPACK domain that reflects the intersection of all three core knowledge areas.

Teacher competencies

Due to the inherently complex and multidimensional nature of teaching, educators require a robust set of knowledge and skills to address the challenges of their roles effectively. Competencies are the combination of cognitive abilities (such as complex thinking, problem-solving, and applying knowledge in specific fields), emotional-motivational attributes (including attitudes, values, and readiness to take action), and behavioral skills (the capacity to effectively utilize one's potential in complex situations) (Mutseekwa, 2025; Peklaj, 2010; Weinert, 2001). Leod, as referenced by Wordu and Isiah (2020), defines teacher competence as the capacity to fulfill responsibilities in a manner that is both responsible and effective. These terms can be further clarified to reflect teaching methods that align with measurable and predefined learning goals, which remain the ultimate aim of any educational endeavor. Wordu and Isiah (2020) emphasize that teachers should demonstrate versatility in their roles, encompassing teaching, counseling, supervision, and evaluation.

Teacher knowledge and digital content integration

Teacher competencies are often framed within the TPACK model, which integrates pedagogical, content, and technological knowledge (Herring et al., 2016). Pedagogical knowledge relates to the art of teaching, content knowledge ensures subject mastery, and technological knowledge allows teachers to use tools like simulations to enhance understanding. The integration of digital content into education requires teachers to possess a blend of pedagogical, content, and technological expertise. Mishra and Koehler's (2006) work established TPACK as a foundation for investigating teacher knowledge in the digital age.

The effectiveness of technological tools depends on teachers' ability to align digital content with curriculum objectives and pedagogical strategies. Teachers with strong TPACK are better equipped to integrate these resources meaningfully, ensuring that they complement rather than replace traditional teaching methods (Mishra and Koehler, 2006).

Numerous studies have utilized the TPACK framework to assess teacher preparedness and identify areas of improvement (Chai et al., 2013; Koehler et al., 2014; Voogt et al., 2013). Schmid et al. (2020) examined self-reported competencies across the TPACK domains and their relation to the integration of digital technologies in lesson planning among 173 pre-service teachers. Their findings revealed no significant group differences in individual TPACK components or TPACK profiles when comparing the use of digital technologies in lesson plans. However, subject group emerged as the only significant predictor, with STEM pre-service teachers showing positive relationships between TPACK components and the inclusion of technology in their lesson plans. Voogt et al. (2013) conducted a systematic review of TPACK studies, highlighting varying interpretations of the framework and its measurement. They emphasized the interconnected nature of teacher knowledge and beliefs about pedagogy and technology, which influence decisions to teach with technology. Active involvement in designing and implementing technology-enhanced lessons was identified as a key strategy for developing TPACK, though limited research addressed subject-specific applications.

One of the challenges in digital content integration is the rapid evolution of educational technologies. Teachers often face difficulty keeping pace with new tools and understanding their pedagogical implications (Koehler et al., 2014). This is particularly true for pre-service teachers, who may lack practical experience in applying digital tools in classroom settings. Studies suggest that professional development programs must be designed to address both technical skills and the pedagogical reasoning behind technology use (Chai et al., 2013). Another challenge lies in the contextual factors influencing TPACK development. For example, teachers working in resource-constrained environments may find it difficult to implement technology-enhanced lessons, regardless of their competencies (Agyei and Voogt, 2011).

Aumann et al. (2024) found that while teachers focus heavily on structuring lessons, they often fail to integrate technology effectively due to insecurities and limited teaching experience. Additionally, Fei and Tse (2023) compared in-service and pre-service biology teachers' readiness for STEM education. They found that while in-service teachers demonstrated stronger subject knowledge, pre-service teachers showed greater enthusiasm for integrating emerging technologies, indicating the need for continuous professional development for both groups.

Structured opportunities for hands-on practice, coupled with reflective learning experiences, have been shown to enhance pre-service teachers' ability to integrate digital tools effectively (Çelik, 2022; Guvercin, 2025; Niess, 2011). For instance, lesson planning exercises that require candidates to align technological tools with specific learning objectives can stimulate deeper understanding and application of TPACK principles. Additionally, collaborative learning environments where teachers share experiences and strategies can facilitate knowledge-building and encourage the adoption of innovative practices (Voogt et al., 2013).

Teacher attitudes toward digital content

Even when teachers possess the necessary technological skills, their beliefs about the value, relevance, and effectiveness of digital tools often determine the extent to which these tools are adopted in their teaching practices (Ertmer et al., 2012; Schreiner and Wiesner, 2023). Teachers who perceive digital tools as essential for improving student engagement and learning outcomes are more likely to integrate them into their lessons (Venkatesh et al., 2003). Conversely, those who view technology as a supplementary or non-essential element often exhibit limited use. Ertmer et al. (2012) emphasized that teacher attitudes are closely linked to their prior experiences with technology.

A key factor influencing teacher attitudes is self-efficacy, the belief in one's ability to successfully perform tasks using technology. Research by Sang et al. (2010) revealed that teachers with higher levels of technological self-efficacy are more likely to embrace digital content. Self-efficacy is shaped by professional development, hands-on practice, and collaborative learning opportunities. Despite the potential benefits of digital content, several barriers can negatively impact teacher attitudes. These include limited access to resources, inadequate training, lack of administrative support, and time constraints (Hew and Brush, 2007). Teachers working in resource-constrained environments often face additional challenges that reinforce negative perceptions of technology. Moreover, cultural and institutional factors can shape attitudes toward digital content. For instance, teachers in environments where traditional teaching methods are emphasized may feel less inclined to adopt innovative practices (Zhao and Frank, 2003). Von Kotzebue (2022) examined the relationship between TPACK beliefs, self-reported knowledge, and the quality of lesson planning among biology teachers. Their study revealed that performance-assessed TPACK, rather than self-reported knowledge, significantly predicted lesson planning quality.

Gender is one of the demographic factors influencing teacher attitudes and competencies related to digital content use. Research suggests that male teachers often report higher confidence in using technology compared to their female counterparts, particularly in contexts where technology use has traditionally been perceived as a male-dominated domain (Kay, 2006; Venkatesh et al., 2003). For example, Sánchez Prieto et al. (2020) examined the digital teaching competence of educators and found that while teachers' knowledge of ICT resources was generally moderate and improvable, there were no significant gender differences in the application of e-skills.

The influence of teaching experience and age on technology integration is complex. Tweed (2013) found that teacher age, years of teaching experience, and hours spent in professional development did not significantly impact self-efficacy or classroom technology use, emphasizing that self-efficacy is the primary driver of successful integration. Similarly, Bakar et al. (2020) observed no significant differences between genders or teaching experience in mathematics teachers' self-efficacy and TPACK. Instead, teachers demonstrated positive self-efficacy in technology integration regardless of these factors. However, experienced teachers bring valuable pedagogical knowledge that can enhance the meaningful use of digital tools (Bertrand et al., 2023). Research by Tondeur et al. (2012) shows the importance of providing tailored training programs that address the specific needs of teachers at different career stages, bridging the gap between digital fluency and pedagogical expertise.

Institutional factors significantly influence teachers' ability to integrate digital content. Schools with strong administrative support, access to technological resources, and a culture of collaboration are more likely to foster positive attitudes toward technology use (Tondeur et al., 2008). Conversely, resource-constrained environments often limit teachers' opportunities to experiment with and adopt digital tools, reinforcing skepticism or reluctance (Agyei and Voogt, 2011). The role of professional learning communities within institutions is another critical factor. Collaborative environments where teachers share best practices and support each other in technology integration can boost confidence and competence. Institutions that prioritize ongoing professional development and mentorship programs also see higher rates of effective digital content use (Kopcha, 2012).

Technology usage in biology education

Biology, as a discipline, heavily relies on visual representations, interactive models, and simulations to explain complex systems and processes. It often involves teaching abstract concepts, such as cellular processes, genetic mechanisms, and ecological interactions, which are difficult for students to visualize. Digital content such as virtual labs, animations, and augmented reality can transform traditional teaching approaches, making abstract and dynamic biological phenomena more accessible and engaging for students (Smetana and Bell, 2012). For example, research by Rutten et al. (2012) found that simulations in biology classrooms significantly enhance students' conceptual understanding and critical thinking skills.

Virtual labs and simulations provide opportunities for students to conduct experiments in a controlled, risk-free environment, fostering curiosity and critical thinking skills (De Jong et al., 2013). Irdalisa and Djukri (2020) found that technology-based guided inquiry significantly enhanced pre-service biology teachers' TPACK, particularly in CK, PK, and TK. Bwalya et al. (2024) reported similar results, showing that a TPACK-based training course positively impacted pre-service teachers' TPACK development through microteaching, reflection, and collaborative lesson planning.

Von Kotzebue (2023) introduced and validated a biology-specific performance assessment for TPACK's technological dimensions, demonstrating that self-report and performance-based measures can provide complementary insights. Their findings revealed that TK did not directly influence TPACK, supporting a transformative view of the framework. Nuruzzakiah et al. (2022) analyzed TPACK competencies among biology teachers, finding that while PK was the strongest component, TK was weaker. No significant differences were observed based on teacher certification or teaching experience. Similarly, Putri et al. (2020) identified challenges in integrating TPACK for teaching biology's classification of living things, with all participating teachers categorized as "pre-TPACK." O'Connor et al. (2018) state that challenges may arise during the incorporation of digital content in biology education. According to Aumann et al. (2024), "teaching scientific content requires visualizing invisible or abstract and complex concepts... and utilizing digital technology such as animations or simulations can contribute to overcoming this challenge."

It has been observed that a lack of digitalization-related competencies among teachers has led to the limited deployment of technology in teaching biology (Aumann et al., 2024). As a result, scholars such as Alavi et al. (2016) have suggested that teacher training should include the use of computers and tablets to support assistive and interactive learning. Alavi et al. (2016) emphasize that teachers should become familiar with computers for step-by-step instructional applications, which could enhance student learning. They further argue that teachers should reevaluate traditional approaches to education and focus on students' visual-display learning modalities to aid cognitive processing of ideas aligned with lesson objectives.

Methods

Sample

The demographic data of the participants reveals that they come from three universities, with the highest percentage (40%) attending the Almaty Humanitarian and Economic University (AHEU) followed (31%) by Suleyman Demirel University (SDU), and Al-Farabi Kazakh National University [(KazNU), (29%)]. Regarding gender distribution, 74% of the participants are female, while 26% are male. Most participants are in their first year (28%), followed by second-year students (36%), third-year students (22%), fourth-year students (14%). The average GPA is 3.5, with a standard deviation of 0.49, indicating moderate variation in academic performance. Regarding financial support, 28% of the participants do not receive stipends, while 72% are supported financially. Among the participants, 59% graduated from public school, 21% from a Lyceum, and 18% from a Gymnasium. The mean score for the university entrance exam is 102 (where maximum score is 140), with a standard deviation of 20, reflecting a range of academic abilities among the participants.

There are differences about institutional policies, technological infrastructure, and training opportunities across AHEU, SDU, and KazNU in TPACK competencies and digital content use. SDU maintains strong international partnerships through programs like Erasmus+, and it has invested in digital infrastructure such as multimedia classrooms and online learning platforms (Foundation for International Business Administration Accreditation [2024, September 13]). AHEU, focuses on accessibility and practical training, particularly in pedagogy, economics, and information technology. The university supports online learning and offers programs in educational technology. Teacher training emphasizes applied skills and includes introductory training in digital tools and blended learning methods. KazNU participates in national digital initiatives such as "Digital Kazakhstan" and has implemented university-wide platforms like "univer.kaznu.kz" and a MOOC system via Open edX. The university hosts a Faculty of Information Technology, yet the integration of digital tools into pedagogical training varies across faculties.

Design

This study employed a quantitative, cross-sectional survey design to examine the levels of teacher knowledge, attitude, and digital content use among future biology teachers, as well as to explore differences across various demographic groups, including gender, grade level, and institutional affiliation. In this design, data were collected at a single point in time using structured surveys, providing a snapshot of the participants' knowledge and digital content use during the study period. A convenience sampling method was used to recruit participants from three universities in Kazakhstan.

Instruments

The first survey, developed by Schmid et al. (2020), was specifically designed to assess pre-service teachers' TPACK, based on the widely recognized TPACK framework. The development of this instrument involved item adaptations from previous validated TPACK surveys, specifically Schmid et al. (2020), to suit the pre-service secondary school teacher population. Items were formulated to ensure applicability across various teaching subjects and contexts, making the instrument versatile. The initial survey consisted of 42 items, which were later refined through reliability and confirmatory factor analyses to ensure that each subscale appropriately captured the relevant aspects of teacher knowledge. The final version of the survey was shown to be both reliable and valid for assessing TPACK, with Cronbach's alphas ranging from 0.77 to 0.91 across subscales, indicating strong internal consistency.

The second survey, developed by the researchers of this study, focuses on assessing teachers' level of use and attitudes toward digital content in their teaching practices. It includes five dimensions and 26 items: frequency of Digital Content Use (FDCU-five items), Types of Digital Content (TDC-five items), Integration into Curriculum (IIC-five items), Technological Proficiency (TP-five items), and Attitudes Toward Digital Content (ATDC-six items).

The FDCU measures how often teachers incorporate digital content into their teaching practices. It captures their routine behaviors in using digital resources such as videos, simulations, and online materials. An example item from this subscale is, "I regularly incorporate digital content (videos, simulations, online resources) in my biology teaching practices." The TDC assesses the variety of digital tools and formats teachers use in their instruction. It reflects teachers' adaptability and flexibility in selecting digital content to suit different lesson objectives. An example item is, "I use a variety of digital content types based on the lesson objectives." The IIC evaluates the extent to which teachers intentionally align digital content with learning objectives during lesson planning. This subscale focuses on how systematically digital resources are incorporated into the curriculum. For example, one item states, "I align digital content with specific learning objectives in my lessons." The TP, measures teachers' self-efficacy and confidence in using digital technologies for instructional purposes. It reflects their perceived competence in employing digital tools effectively. This construct is informed by prior research on technological self-efficacy (Sang et al., 2010). An illustrative item is, "I feel very confident in using various digital tools and platforms for teaching biology." The ATDC examines teachers' affective and motivational orientations toward the use of digital resources in biology education. This subscale draws on the Technology Acceptance Model (Venkatesh et al., 2003) to capture participants' beliefs, enthusiasm, and openness to integrating digital content. An example item is, "I believe that using digital content enhances the overall learning experience for students." Participants responded using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

The validation process for this survey involved multiple steps. Initially, the items were developed and refined through discussions among the authors of the study. This internal review ensured that the survey comprehensively addressed the target constructs. Following this, two experts in the field of information technology education were consulted to review the survey. These experts provided feedback on the clarity, relevance, and appropriateness of the items, ensuring the survey's content validity. Their input led to further revisions, enhancing the survey's alignment with the research objectives and improving its overall reliability and validity. Table 1 presents the Cronbach α coefficients of the surveys' dimensions.

The reliability analysis for the dimensions of the two surveys indicates acceptable internal consistency across most constructs, as measured by Cronbach's alpha values. For the teacher knowledge survey, Cronbach's alpha values ranged from 0.71 to 0.85, indicating good internal consistency across the various knowledge domains,

TABLE 1 Cronbach α coefficients of the surveys' dimensions.

Dimension	Cronbach α
Pedagogical knowledge	0.68
Content knowledge	0.76
Technological knowledge	0.79
Pedagogical content knowledge	0.79
Technological pedagogical knowledge	0.75
Technological pedagogical content knowledge	0.75
Frequency of digital content use	0.77
Types of digital content	0.69
Integration into curriculum	0.68
Technological proficiency	0.73
Attitudes toward digital content	0.76

including pedagogical, content, and technological knowledge, as well as their combinations. For the digital content use and attitudes survey, the reliability scores ranged from 0.68 to 0.79, reflecting acceptable consistency in measuring constructs such as FDCU, TDC, IIC, and ATDC. One item in the TDC scale was removed because the Cronbach's alpha increased from 0.63 to 0.71 when this item was dropped, leading to improved internal consistency.

The surveys were originally developed in English and translated into Kazakh to accommodate the participants from Kazakhstan. The translation process involved a review by two instructors specializing in Information Technology Education, both proficient in Kazakh and English. After the initial translation was completed, the two instructors carefully reviewed the translated version to ensure clarity and accuracy. During this process, they worked together to resolve any discrepancies or differences in interpretation. Any disputes or uncertainties regarding specific terms or phrasing were discussed and resolved between the instructors themselves. Following their review and feedback, the authors refined the translation, ensuring that the final Kazakh version was both accurate and contextually appropriate for the participants. Finally, two students read aloud while completing the surveys. This process was successful, resulting in no comments or concerns from the students.

Data collection

The surveys were distributed through a Google Form, which included both instruments administered simultaneously to all participants. The total time required for students to complete both surveys was approximately 20 min. Initially, 252 students provided responses, but several were excluded due to participants selecting the same option throughout the survey or not completing it. After cleaning the data, a total of 240 responses remained for analysis.

The Google Form was distributed through colleagues from three universities in Kazakhstan: AHEU, KazNU, and SDU. Given the relatively small number of biology education students at each university, data was collected from these three institutions to ensure a sufficient sample size for the analyses. Students completed the survey using their personal mobile phones or computers during course hours.

Data analyses

The results section presents the findings of the statistical analyses conducted to examine differences in teacher knowledge and digital content use among pre-service teachers across various demographic groups, including gender, grade level, and institutional affiliation. The analyses employed non-parametric tests, including the Mann-Whitney U test and the Kruskal-Wallis test, followed by Dwass-Steel-Critchlow-Fligner pairwise comparisons. Correlational analyses was run to reveal the relationships between the dimensions of the surveys.

The effect sizes for the Mann-Whitney *U* tests were reported using the rank biserial correlation coefficient (r), a commonly used measure for non-parametric comparisons. Following conventional guidelines, effect sizes were interpreted as negligible ($r < 0.10$), small ($r = 0.10$ to 0.19), small-to-medium ($r = 0.20$ to 0.29), medium ($r = 0.30$ to 0.49), and large ($r \geq 0.50$) (Fritz et al., 2012).

Results

The results section provides an overview of the descriptive and inferential statistics for the Teacher Knowledge and Digital Content Use surveys. Descriptive analyses reveal high self-reported knowledge levels across various domains, such as Pedagogical, Content, and Technological Knowledge, though there is variability in responses. Significant differences emerge between groups based on gender, stipend status, and institutional affiliation, indicating varied impacts on teachers' knowledge and digital content use. Table 2 is designed to represent descriptives statistics for the dimensions of the surveys.

The mean and median scores for all dimensions, such as PK, CK, TK, and their integrated forms PCK, TPK, TCK, and TPACK, range from 2.96 to 4.51, and 2.80 to 4.50 respectively, indicating high levels of self-reported knowledge. The standard deviations are moderate, indicating some variability in responses. For the Teachers' Level of Use and Attitude Toward Digital Content survey, the results show a broad range of experiences and attitudes. The median scores for the use of digital content, such as FDCU, and ICC, are lower (all 3.40) compared to the ATDC which has a high median score of 4.50. TP has the lowest median score (2.80).

Gender

The Mann-Whitney U tests were conducted (Table 3) to compare male and female pre-service teachers across the dimensions of the both surveys because normality test though Shapiro-Wilk yielded non-normal distribution for both female and male students' data.

After applying the Bonferroni correction (cognitive $\alpha = 0.0083$; affective–motivational $\alpha = 0.010$), significant gender differences were found in PK and TPCK ($p = 0.004$ and $p < 0.001$

TABLE 2 Descriptives statistics for the dimensions of the surveys.

Dimension	Missing	Mean	Median	SD	Dimension	Missing	Mean	Median	SD
PK	2	4.51	4.50	0.50	FDCU	12	3.45	3.40	0.39
CK	2	4.30	4.25	0.60	TDC	8	3.96	4.00	0.42
TK	2	4.46	4.50	0.56	IIC	8	3.43	3.40	0.48
PCK	2	4.39	4.50	0.53	TP	6	2.96	2.80	0.53
TPK	2	4.46	4.50	0.50	ATDC	6	4.45	4.50	0.44
TCK	2	4.38	4.50	0.55					
TPCK	0	4.37	4.50	0.59					

TABLE 3 Mann-Whitney *U* test results and effect sizes (ε^2) comparing gender differences across survey dimensions.

Dimension	Statistic	*P*	Median		Effect size[a]
			Female	Male	
PK	3,876	**0.004**[b]	4.56	4.31	−0.25
CK	4,890	0.54	4.31	4.24	−0.05
TK	4,090	0.015	4.41	4.32	−0.21
PCK	4,012	0.009	4.46	4.21	−0.22
TPK	4,288	0.047	4.49	4.35	−0.17
TCK	4,860	0.498	4.38	4.40	−0.06
TPCK	3,626	**<0.001**	4.45	4.12	−0.32
FDCU	4,340	0.298	3.47	3.41	−0.09
TDC	3,108	**<0.001**	4.03	3.75	−0.36
IIC	4,640	0.585	4.42	4.45	0.05
TP	4,802	0.769	2.98	2.91	−0.03
ATDC	3,804	**0.004**	4.51	4.28	−0.25

[a]Effect size is measured as Rank biserial correlation.
[b]Significant *p* values are bolded.

respectively, cognitive domain), TDC and ATDC ($p < 0.001$ and $p = .004$ respectively, affective–motivational domain) with female pre-service teachers scoring higher in all four variables. No other domains showed significant gender differences under the corrected alpha levels. The largest effect sizes were observed for TDC (−0.36) and TPCK (−0.32), both indicating moderate effects, showing meaningful gender-related differences in these areas.

Stipend

The Mann-Whitney *U* test was used to examine (Table 4) whether receiving a stipend had a significant impact on the dimensions of the both surveys because the normality test though Shapiro-Wilk yielded non-normal distribution for both those receive and do not receive stipend.

The results indicate that for most dimensions, there were no significant differences between teachers who received a stipend and those who did not. However, following Bonferroni correction, a significant difference was observed only in TK ($p = 0.001$, cognitive domain), with stipend recipients scoring higher than non-recipients. No other cognitive or affective–motivational variables reached significance under the corrected thresholds. In this analysis, TK (0.26) exhibited the largest effect size, representing a small-to-medium difference across the comparison groups, with stipend recipients scoring higher than non-recipients. Small to negligible effects were observed for the remaining dimensions.

Grade level

The Kruskal-Wallis test was used (Table 5) to examine the effect of grade level on the various dimensions of the Teacher Knowledge survey. Significant differences were found for several dimensions. Due to 12 dimensions of the two surveys Bonferroni adjustment was done on the alpha level which is $0.05/12 = 0.00417$.

Among the 12 dimensions analyzed, only PCK showed a statistically significant difference across grade levels after applying the Bonferroni correction ($\chi^2 = 16.60$, $df = 4$, $p = 0.002$), as its p-value falls below the adjusted alpha level of 0.00417. The corresponding effect size ($\varepsilon^2 = 0.06$) suggests a moderate practical effect of grade level on PCK. *Post-hoc* pairwise comparisons using

TABLE 4 Mann-Whitney *U* test results and effect sizes (ε^2) comparing stipend differences across survey dimensions.

Dimension	Statistic	P	Median		Effect size[a]
			No	Yes	
PK	5,110	0.223	4.45	4.54	0.10
CK	4,804	0.062	4.17	4.35	0.15
TK	4,186	**0.001**[b]	4.50	4.71	0.26
PCK	4,894	0.093	4.25	4.50	0.14
TPK	5,498	0.702	4.50	4.50	0.03
TCK	5,480	0.676	4.41	4.37	0.03
TPCK	5,482	0.444	4.38	4.36	0.06
FDCU	5,050	0.492	3.48	3.44	−0.06
TDC	5,082	0.382	3.98	3.97	0.07
IIC	5,184	0.515	3.39	3.44	0.05
TP	4,992	0.225	2.97	2.95	−0.10
ATDC	4,544	0.048	4.36	4.48	0.16

[a]Effect size is measured as Rank biserial correlation.
[b]Significant *p* values are bolded.

TABLE 5 Kruskal-Wallis test results and effect sizes (ε^2) comparing grade level differences across survey dimensions.

Dimensions	χ^2	df	P	ε^2
PK	9.74	4	0.045	0.04
TK	3.14	4	0.534	0.01
PCK	16.60	4	**0.002**	0.06
TPK	7.84	4	0.098	0.03
TCK	8.91	4	0.063	0.03
TPACK	11.44	4	0.022	0.04
FDCU	8.63	4	0.071	0.03
TDC	10.15	4	0.038	0.04
IIC	7.28	4	0.122	0.03
TP	4.92	4	0.295	0.02
ATDC	5.20	4	0.268	0.02

Significant *p* values are bolded.

the Dwass–Steel–Critchlow–Fligner test revealed that significant difference was observed for PCK where both first-year ($p = 0.008$) and second-year students ($p = 0.023$) scored significantly lower than their third-year peers.

University

The Kruskal-Wallis test results (Table 6) for the effect of institutional affiliation on the Teacher Knowledge survey dimensions reveal significant differences across all knowledge domains. Due to 12 dimensions of the two surveys Bonferroni adjustment was done on the alpha level which is 0.05/12 = 0.00417.

TABLE 6 Kruskal-Wallis test results and effect sizes (ε^2) comparing institutional differences across survey dimensions.

Dimensions	χ^2	df	P	ε^2
PK	20.13	2	**<0.001**	**0.08**
CK	35.76	2	**<0.001**	**0.15**
TK	47.72	2	**<0.001**	0.20
PCK	28.14	2	**<0.001**	0.12
TPK	22.6	2	**<0.001**	0.10
TCK	21.2	2	**<0.001**	0.09
TPCK	26.08	2	**<0.001**	0.11
FDCU	1.05	2	0.59	0.00
TDC	7.43	2	0.024	0.03
IIC	1.33	2	0.515	0.01
TP	10.12	2	0.006	0.04
ATDC	2.51	2	0.286	0.01

Significant *p* values are bolded.

The findings reveal statistically significant differences across universities in several key areas of teacher competence and digital integration, even after applying the Bonferroni-adjusted alpha level of 0.00417. Significant differences were observed in PK ($\chi^2 = 20.13$, $p < 0.001$, $\varepsilon^2 = 0.08$), CK ($\chi^2 = 35.76$, $p < 0.001$, $\varepsilon^2 = 0.15$), TK ($\chi^2 = 47.72$, $p < 0.001$, $\varepsilon^2 = 0.20$), PCK ($\chi^2 = 28.14$, $p < 0.001$, $\varepsilon^2 = 0.12$), TPK ($\chi^2 = 22.60$, $p < 0.001$, $\varepsilon^2 = 0.10$), TCK ($\chi^2 = 21.20$, $p < 0.001$, $\varepsilon^2 = 0.09$), and TPCK ($\chi^2 = 26.08$, $p < 0.001$, $\varepsilon^2 = 0.11$). Pairwise comparisons with Bonferroni-adjusted alpha ($\alpha = 0.017$) showed consistent patterns of institutional differences. Students from both SDU and AHEU outperformed KazNU in PK, CK, PCK, TCK, and TPCK (all $p < 0.01$). In TK, AHEU scored significantly higher than both SDU and KazNU ($p < 0.001$), while SDU and KazNU did not differ. For TPK, only AHEU scored higher than KazNU ($p < 0.001$). Finally, in the affective–motivational domain, TP scores were significantly higher for AHEU than KazNU ($p = 0.006$).

Correlational analyses

Table 7 presents the Spearman's rank-order correlation coefficients between the dimensions of the two surveys, including teacher knowledge domains (TPACK components), digital content use variables, and attitudes toward digital content.

The correlation matrix revealed several significant relationships among the survey dimensions. Notably, TDC was strongly and positively correlated with multiple teacher knowledge domains, including PK; $\rho = 0.30$, $p < 0.001$), CN; $\rho = .34$, $p < 0.001$), TK; $\rho = 0.28$, $p < 0.001$), PCK; $\rho = 0.40$, $p <.001$), TPK; $\rho = 0.37$, $p < 0.001$), TCK; $\rho = 0.37$, $p < 0.001$), and TPCK; $\rho = 0.50$, $p < 0.001$), indicating that greater perceived professional knowledge is associated with more diverse digital content use. Similarly, FDCU showed small but significant positive correlations with TK ($\rho = 0.14$, $p = 0.038$), PCK ($\rho = 0.13$, $p = 0.044$), TPK ($\rho = 0.30$, $p < 0.001$), TCK ($\rho = 0.34$, $p < 0.001$), and TPCK ($\rho = 0.26$, $p < 0.001$).

TABLE 7 Spearman's rank-order correlations between the two survey dimensions.

	PK	CN	TK	PCK	TPK	TCK	TPCK
FDC	0.13*	0.06	0.14*	0.13*	0.30***	0.34***	0.26***
TDC	0.30***	0.34***	0.28***	0.40***	0.37***	0.37***	0.50***
IIC	0.02	0.06	−0.01	0.05	0.15*	0.12	0.13*
TP	−0.20**	−0.1	−0.24***	−0.08	−0.13	−0.23***	−0.15*
ATDC	0.18**	0.11	0.13*	0.12	0.25***	0.21**	0.23***

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

In contrast, TP displayed small negative correlations with PK ($\rho = -0.20$, $p = 0.003$), TK ($\rho = -0.24$, $p < 0.001$), TCK ($\rho = -0.23$, $p < 0.001$), and TPCK ($\rho = -0.15$, $p = 0.024$), showing that lower perceived technological proficiency may be linked to higher self-reported knowledge in some areas. Lastly, ATDC showed positive correlations with PK ($\rho = 0.18$, $p = 0.006$), TK ($\rho = 0.13$, $p = 0.044$), TPK ($\rho = 0.25$, $p < 0.001$), TCK ($\rho = 0.21$, $p = 0.002$), and TPCK ($\rho = 0.23$, $p = 0.002$), indicating that more favorable attitudes are associated with higher levels of professional knowledge. No significant correlations were observed between Integration IIC and most variables.

Discussion

A particularly notable finding is the significant impact of stipend status on TK, while other TPACK dimensions remained unaffected. This suggests that financial support may provide pre-service teachers with access to technology and training, enhancing their technological proficiency. The role of financial stability in influencing specific competencies is especially relevant in contexts where access to technological resources might be unevenly distributed. Another distinctive result is the pronounced variability in TK scores across institutions. Students from AHEU and SDU outperformed those from KazNU, suggesting disparities in technological training and resource allocation within the same national education system. These findings call attention to the contextual nature of teacher preparation and the importance of equitable access to technology and related support.

These findings align with and expand upon existing literature. The high self-reported competencies in PK, CK, and TK are consistent with studies such as Durdu and Dag (2017), which observed significant improvements in pre-service teachers' TPACK competencies following targeted instructional interventions. However, Hahn et al. (2022) caution that self-reported competencies may not always reflect actual proficiency.

Gender-related differences in TPACK competencies have been noted in previous research, though findings are mixed. Female participants in this study exhibited higher competencies in Pk, PCK, TPK, and TPACK, as well as more positive attitudes toward digital content. Hahn et al. (2022) reported higher confidence among male pre-service teachers in certain technological skills, while Wang et al. (2020) found that female pre-service teachers had better control of subject teaching knowledge. Bakar et al. (2020) observed no significant differences in CK or TCK based on gender. These discrepancies shows that contextual factors, including cultural norms and educational environments, play a significant role in shaping gender-related differences.

Institutional differences were significant, with students from AHEU and SDU outperforming those from KazNU in most TPACK dimensions. This aligns with Tondeur et al. (2012) and Kopcha (2012), who emphasized the critical role of institutional support and resources in developing pre-service teachers' TPACK competencies. Institutional strategies, such as providing role models and authentic technology experiences, are instrumental in enhancing teacher preparation. While Ruggiero and Mong (2015) acknowledged the impact of external factors such as resource availability, their study emphasized that overcoming internal barriers, such as personal investment, attitudes toward technology, and peer support, plays a crucial role in successful technology adoption in educational settings.

Grade-level differences indicated that competencies improved over time, with final year students demonstrating greater integration of pedagogy, content, and technology. This finding aligns with Durdu and Dag (2017), who found the positive impact of structured, TPACK-based courses on pre-service teachers' competency development as they progress through their education.

Despite positive attitudes toward digital content, participants reported lower frequency of use and technological proficiency. This gap between attitude and practice is reflected in the literature. Hahn et al. (2022) noted that while pre-service teachers may express confidence in their digital competencies, this does not always translate into actual classroom integration, often due to barriers such as limited access to technology or insufficient training. This gap may stem from systemic and contextual barriers. For example, curriculum overload may leave little time or flexibility for experimenting with digital tools, especially in rigid, exam-driven instructional contexts. Moreover, resistance to change, either internal (e.g., fear of making mistakes with unfamiliar tools) or external (e.g., mentor teachers modeling traditional practices during practicum), may discourage the translation of attitudes into action.

This study employed a convenience sampling method, selecting participants based on their availability and accessibility from three universities. While this approach allowed for timely data collection from a diverse cohort of pre-service biology teachers, it also introduces potential limitations that must be acknowledged. Moreover, the overrepresentation of female participants (74%)

might skew gender-related findings. Although the sample included students from varied grade levels and institutions to enhance variability, future studies should consider employing stratified or random sampling techniques to ensure greater representativeness and mitigate selection bias.

The findings of this study contribute to the theoretical understanding of teacher competence in the digital era by demonstrating how professional knowledge, digital content use, and attitudes toward digital tools are interconnected among pre-service biology teachers. The results support competence models such as the COACTIV framework (Baumert and Kunter, 2013), which emphasize the importance of both cognitive and affective-motivational components in teacher competence. Furthermore, the strong associations between technological knowledge domains and digital content use provide empirical backing for the TPACK framework (Mishra and Koehler, 2006), showing the relevance of integrated technology-related competencies in teacher preparation. This study extends previous research by showing that both technical knowledge and attitudes toward digital content play a crucial role in predicting technology use in biology education.

Although this study was conducted with pre-service biology teachers from three specific universities in Kazakhstan, the findings may have broader implications for teacher education in similar contexts. The consistent relationships observed between professional knowledge, digital content use, and attitudes suggest that these dynamics are not unique to the participating institutions, but may also apply to other teacher education programs facing similar challenges with digital integration. In particular, teacher education programs in countries with emerging digital infrastructures or similar educational policies may benefit from considering these results when designing their digital competence training initiatives. While institutional contexts can influence digital learning environments, the observed patterns likely reflect common needs and barriers experienced by pre-service teachers elsewhere. Nevertheless, future research is encouraged to replicate and extend this study in diverse institutional and national contexts to strengthen generalizability.

Conclusion and implications

This study investigated the competencies, attitudes, and digital content usage of pre-service biology teachers in Kazakhstan, with a focus on demographic and institutional factors influencing TPACK. The findings revealed high self-reported competencies across TPACK domains, with notable variations in TK and attitudes toward digital content across gender, grade level, and institutional contexts. Female participants consistently demonstrated higher competencies in several domains, while senior students showed greater integration of pedagogy, content, and technology, indicating the developmental impact of teacher education programs.

Institutional differences highlighted the critical role of educational environments, as students from AHEU and SDU consistently outperformed those from KazNU in TPACK competencies. These disparities show the importance of resource allocation and targeted institutional strategies to foster technological integration in teacher preparation. Moreover, the significant impact of stipend status on TK suggests that financial support may indirectly enhance access to resources and training, particularly in resource-constrained environments.

Despite participants' positive attitudes toward digital content, their relatively low frequency of use and technological proficiency suggest a gap between enthusiasm and practical application. This points to a need for teacher preparation programs to prioritize hands-on experiences and reflective practices that connect digital tools to pedagogical objectives.

The study contributes to the literature by providing a comprehensive understanding of pre-service biology teachers' competencies and their interactions with demographic and institutional factors in a developing education system. Future research should explore longitudinal changes in TPACK competencies, incorporate performance-based assessments, and investigate the influence of specific interventions designed to bridge the gap between attitudes and practice.

To address the identified gaps between positive attitudes and limited digital content use, as well as institutional and demographic disparities in TPACK competencies, teacher education programs should implement evidence-based interventions. First, mandatory hands-on digital integration workshops should be added to the core curriculum, requiring pre-service teachers to design and deliver lesson plans using specific types of digital content (e.g., simulations, virtual labs). Second, structured mentoring systems involving collaboration between technologically experienced faculty members and pre-service teachers can be beneficial for practical modeling and support, particularly for students from institutions with lower technological exposure. Third, the development of equity-focused modules is recommended to ensure that gender and financial status do not limit access to digital tools, including subsidized software access and technology grants for students in need. Finally, the integration of performance-based assessments (e.g., video-recorded teaching with rubric-based evaluations of digital integration) would allow for authentic evaluation of digital competencies beyond self-reports.

The practical implications of this study are particularly relevant for teacher education programs and educational policymakers. Given the significant associations between professional knowledge, attitudes, and digital content use, teacher training programs should prioritize both technological skill development and attitude-enhancing interventions. Integrating practical workshops, hands-on digital projects, and reflective activities aimed to increase positive attitudes toward digital teaching tools may help pre-service teachers develop more effective and confident digital teaching practices. Additionally, the observed differences across universities shows that institutional factors can influence digital competence development, indicating the need for consistent, high-quality digital education opportunities across different teacher preparation institutions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Abai Kazakh National Pedagogical University Ethical Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

AA: Data curation, Writing – original draft. KZ: Conceptualization, Writing – original draft. MS: Conceptualization, Writing – review & editing. TY: Formal analysis, Writing – review & editing. AM: Methodology, Writing – original draft. NB: Supervision, Writing – review & editing.

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References

Agyei, D. D., and Voogt, J. (2011). Exploring the potential of the will, skill, tool model in Ghana: predicting prospective and practicing teachers' use of technology. *Comp. Educ.* 56, 91–100. doi: 10.1016/j.compedu.2010.08.017

Alavi, S. M., Borzabadi, D., and Dashtestani, R. (2016). Computer literacy in learning academic English. Iranian EAP students‘ and instructors' attitudes and perspectives. *Teach. English Technol.* 16, 56–77.

Aumann, A., Schnebel, S., and Weitzel, H. (2024). Teaching biology lessons using digital technology: a contextualized mixed-methods study on pre-service biology teachers' enacted TPACK. *Educ. Sci.* 14:538. doi: 10.3390/educsci14050538

Bakar, N. S. A., Maat, S. M., and Rosli, R. (2020). Mathematics teacher's self-efficacy of technology integration and technological pedagogical content knowledge. *J. Math. Educ.* 11, 259–276. doi: 10.22342/jme.11.2.10818.259-276

Baumert, J., and Kunter, M. (2013). "The COACTIV model of teachers' professional competence," in *Cognitive Activation in the Mathematics Classroom and Professional Competence of Teachers*, eds. M. Kunter, J. Baumert, W. Blum, U. Klusmann, S. Krauss, and M. Neubrand (Springer), 25–48. doi: 10.1007/978-1-4614-5149-5_2

Bertrand, M. G., Namukasa, I. K., and Li, L. (2023). STEAM camp: teaching middle school students mathematics, science and coding through digital designs. *J. Res. Sci. Math. Technol. Educ.* 6, 47–67. doi: 10.31756/jrsmte.213SI

Bwalya, A., Rutegwa, M., and Mapulanga, T. (2024). Developing pre-service biology teachers' technological pedagogical content knowledge through a TPACK-based course. *Eur. J. Educ. Res.* 13, 263–278. doi: 10.12973/eu-jer.13.1.263

Çelik, Y. (2022). Determining the opinions of classroom teachers and classroom teacher candidates regarding the education they received before service. *Eur. Educ. Res.* 5, 149–176. doi: 10.31757/euer.522

Chai, C. S., Koh, J. H. L., and Tsai, C-. C. (2013). A review of technological pedagogical content knowledge. *Educ. Technol. Soc.* 16, 31–51.

De Jong, T., Linn, M. C., and Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science* 340, 305–308. doi: 10.1126/science.1230579

Durdu, L., and Dag, F. (2017). Pre-service teachers' TPACK development and conceptions through a TPACK-based course. *Aust. J. Teacher Educ.* 42, 150–171. doi: 10.14221/ajte.2017v42n11.10

Ertmer, P. A., Ottenbreit-Leftwich, A. T., Sadik, O., Sendurur, E., and Sendurur, P. (2012). Teacher beliefs and technology integration practices: a critical relationship. *Comp. Educ.* 59, 423–435. doi: 10.1016/j.compedu.2012.02.001

Fei, C., and Tse, A. W. C. (2023). Examining the technological pedagogical content knowledge (TPACK) of biology educators: a case study on pre-service and in-service teachers in preparation for applying STEM education. *Int. Symp. Emerg. Technol. Educ.* 14606. doi: 10.1007/978-981-97-4243-1_8

Foundation for International Business Administration Accreditation (2024). *Decision of the FIBAA Accreditation and Certification Committee: Assessment Report for Program Accreditation (Project No. 22/059 Cluster 1)*. Bonn: Foundation for International Business Administration Accreditation.

Fritz, C. O., Morris, P. E., and Richler, J. J. (2012). Effect size estimates: current use, calculations, and interpretation. *J. Exp. Psychol. Gen.* 141, 2–18. doi: 10.1037/a0024338

Grechi, D., Mardenova, L. K., and Yessimzhanova, S. (2025). Choosing a major in the age of digital influence: a comparative study of Generation Z in Kazakhstan and Italy. *Front. Educ.* 10:1587611. doi: 10.3389/feduc.2025.1587611

Guvercin, S. (2025). The urgent case for AI literacy in the 21st century. *Int. Educ. Rev.* 3, 41–44. doi: 10.58693/ier.313

Hahn, S., Pfeifer, A., and Kunina-Habenicht, O. (2022). Multiple facets of self-rated digital competencies of pre-service teachers: a pilot study on the nomological network, empirical structure, and gender differences. *Front. Educ.* 7:999679. doi: 10.3389/feduc.2022.999679

Herring, M. C., Koehler, M. J., and Mishra, P. (2016). *Handbook of Technological Pedagogical Content Knowledge (TPACK) for Educators, Vol. 3* (New York: Routledge), 189–200. doi: 10.4324/9781315771328

Hew, K. F., and Brush, T. (2007). Integrating technology into K-12 teaching and learning: current knowledge gaps and recommendations for future research. *Educ. Technol. Res. Dev.* 55, 223–252. doi: 10.1007/s11423-006-9022-5

Irdalisa, P., and Djukri. (2020). Implementation of technology-based guided inquiry to improve TPACK among prospective biology teachers. *Int. J. Instr.* 13, 33–44. doi: 10.29333/iji.2020.1323a

Kay, R. H. (2006). Addressing gender differences in computer ability, attitudes, and use: the laptop effect. *J. Educ. Comp. Res.* 34, 187–211. doi: 10.2190/9BLQ-883Y-XQMA-FCAH

Koehler, M. J., Mishra, P., Kereluik, K., Shin, T. S., and Graham, C. R. (2014). "The technological pedagogical content knowledge framework," *in Handbook of Research on Educational Communications and Technology*, eds. J. M. Spector, M. D. Merrill, J. Elen, and M. J. Bishop (New York, NY: Springer), 101–111. doi: 10.1007/978-1-4614-3185-5_9

Kopcha, T. J. (2012). Teachers' perceptions of the barriers to technology integration and practices with technology under situated professional development. *Comp. Educ.* 59, 1109–1121. doi: 10.1016/j.compedu.2012.05.014

Mishra, P., and Koehler, M. J. (2006). Technological pedagogical content knowledge: a framework for teacher knowledge. *Teachers Coll. Rec.* 108, 1017–1054. doi: 10.1111/j.1467-9620.2006.00684.x

Mutseekwa, C. (2025). Towards an integrated model for orienting preservice science teachers for 21st-century teaching. *Int. Educ. Rev.* 3, 1–19. doi: 10.58693/ier.311

Niess, M. L. (2011). Investigating TPACK: knowledge growth in teaching with technology. *J. Educ. Comp. Res.* 44, 299–317. doi: 10.2190/EC.44.3.c

Nuruzzakiah, N., Hasanuddin, H., Artika, W., Supriatno, S., and Rahmatan, H. (2022). Competency analysis of technological pedagogical and content knowledge (TPACK) biology teachers. *Jurnal Penelitian Pendidikan IPA*, 8, 325–335. doi: 10.29303/jppipa.v8i1.1166

O'Connor, A., Seery, N., and Canty, D. (2018). The experiential domain: developing a model for enhancing practice in D T education. *Int. J. Technol. Des. Educ.* 28, 85–99. doi: 10.1007/s10798-016-9378-8

Peklaj, C. (2010). "Teacher competencies in a knowledge society," in *Teacher Competencies and Educational Goals. Schriften zur Bilduns- und Freizeitwissenschaft, Band 6*, ed. C. Peklaj (Aachen: Shaker Verlag), 37–50.

Putri, A. R. A., Hidayat, T., and Purwianingsih, W. (2020). Analysis of technological pedagogical content knowledge (TPACK) of biology teachers in classification of living things learning. *J. Phys. Conf. Ser.* 1521:042033. doi: 10.1088/1742-6596/1521/4/042033

Ruggiero, D., and Mong, C. J. (2015). The teacher technology integration experience: practice and reflection in the classroom. *J. Inf. Technol. Educ. Res.* 14, 161–178. doi: 10.28945/2227

Rutten, N., van Joolingen, W. R., and van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Comp. Educ.* 58, 136–153. doi: 10.1016/j.compedu.2011.07.017

Sánchez Prieto, J., Trujillo Torres, J. M., Gómez García, M., and Gómez García, G. (2020). Gender and digital teaching competence in dual vocational education and training. *Educ. Sci.* 10:84. doi: 10.3390/educsci10030084

Sang, G., Valcke, M., van Braak, J., and Tondeur, J. (2010). Student teachers' thinking processes and ICT integration: predictors of prospective teaching behaviors with educational technology. *Comp. Educ.* 54, 103–112. doi: 10.1016/j.compedu.2009.07.010

Schmid, M., Brianza, E., and Petko, D. (2020). Self-reported technological pedagogical content knowledge (TPACK) of pre-service teachers in relation to digital technology use in lesson plans. *Comp. Hum. Behav.* 115:106586. doi: 10.1016/j.chb.2020.106586

Schreiner, C., and Wiesner, C. (2023). Modelling digital competence by combining computational thinking with general learning taxonomies. *Eur. Educ. Res.* 6, 21–42. doi: 10.31757/euer.612

Smetana, L. K., and Bell, R. L. (2012). Computer simulations to support science instruction and learning: a critical review of the literature. *Int. J. Sci. Educ.* 34, 1337–1370. doi: 10.1080/09500693.2011.605182

Tondeur, J., van Braak, J., Sang, G., Voogt, J., Fisser, P., Ottenbreit-Leftwich, A., et al. (2012). Preparing pre-service teachers to integrate technology in education: a synthesis of qualitative evidence. *Comp. Educ.* 59, 134–144. doi: 10.1016/j.compedu.2011.10.009

Tondeur, J., van Keer, H., van Braak, J., and Valcke, M. (2008). ICT integration in the classroom: challenging the potential of a school policy. *Comp. Educ.* 51, 212–223. doi: 10.1016/j.compedu.2007.05.003

Tweed, S. (2013). *Technology implementation: teacher age, experience, self-efficacy, and professional development as related to classroom technology integration* (dissertation). East Tennessee State University, Johnson City, TN, United States.

Venkatesh, V., Morris, M. G., Davis, G. B., and Davis, F. D. (2003). User acceptance of information technology: toward a unified view. *MIS Q.* 27, 425–478. doi: 10.2307/30036540

Von Kotzebue, L. (2022). Beliefs, self-reported or performance-assessed TPACK: what can predict the quality of technology-enhanced biology lesson plans? *J. Sci. Educ. Technol.* 31, 570–582. doi: 10.1007/s10956-022-09974-z

Von Kotzebue, L. (2023). Two is better than one-examining biology-specific TPACK and its T-dimensions from two angles. *J. Res. Technol. Educ.* 55, 765–782. doi: 10.1080/15391523.2022.2030268

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., and van Braak, J. (2013). Technological pedagogical content knowledge - a review of the literature. *J. Comp. Assisted Learn.* 29, 109–121. doi: 10.1111/j.1365-2729.2012.00487.x

Wang, Y., Gu, X., and Liu, S. (2020). The investigation and analysis of pre-service teachers toward TPACK competencies. *Open J. Soc. Sci.* 8, 327–339. doi: 10.4236/jss.2020.812027

Weinert, F. E. (2001). "Concept of competence: a conceptual clarification," in *Defining and Selecting Key Competencies*, eds. D. S. Rychen, and L. H. Salganik (Seattle: Hogrefe Huber Publishers), 45–66.

Wordu, H., and Isiah, C. E. (2020). Teachers' competence for effective teaching and learning for the 21st century schools in Nigeria. *Int. J. Appl. Res.* 6, 235–237.

Zhao, Y., and Frank, K. A. (2003). Factors affecting technology uses in schools: an ecological perspective. *Am. Educ. Res. J.* 40, 807–840. doi: 10.3102/00028312040004807

 10.3389/feduc.2025.1628034

Appendix

Survey 2: Teachers' level of use and attitude toward digital content

Yellow highlighted are reverse coded.

A. Frequency of Digital Content Use:

a. I regularly incorporate digital content (videos, simulations, online resources) in my biology teaching practices.

b. I frequently use digital content for planning and designing my biology lessons.

c. Digital content is an integral part of my teaching routine.

d. I occasionally use digital content in my biology lessons.

e. I rarely use digital content for teaching purposes.

B. Types of Digital Content:

a. I prefer using videos as a primary form of digital content in my biology lessons.

b. Interactive simulations are my go-to choice for enhancing student learning in biology.

c. Online textbooks are a valuable resource in my biology curriculum.

d. I use a variety of digital content types based on the lesson objectives.

e. I predominantly rely on traditional teaching methods without much use of digital content.

C. Integration into Curriculum:

a. I seamlessly integrate digital content into my biology curriculum.

b. I align digital content with specific learning objectives in my lessons.

c. The integration of digital content is a deliberate part of my curriculum planning.

d. I sometimes integrate digital content into my lessons, but it's not a consistent practice.

e. I rarely consider digital content when planning my biology curriculum.

E. Technological Proficiency:

a. I feel very confident in using various digital tools and platforms for teaching biology.

b. I have a high level of proficiency in using digital content for educational purposes.

c. I am moderately confident in my ability to effectively use digital tools for teaching.

d. I have some basic skills in using digital tools, but I need improvement.

e. I lack confidence in using digital tools and platforms for teaching biology.

F. Attitudes Toward Digital Content:

a. I have a positive attitude toward incorporating digital content in my biology lessons.

b. I believe that using digital content enhances the overall learning experience for students.

c. I am enthusiastic about exploring new digital tools and resources for teaching biology.

d. I feel optimistic about the potential impact of digital content on student engagement.

e. I am open to experimenting with different forms of digital content in my teaching.

f. I view digital content as a valuable addition to traditional teaching methods in biology.